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THE ROLE OF TREES IN DRYLAND SALINITY CONTROL

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Abstract: Tree planting is likely to play a part in control strategies for dryland salting, due to the high annual water use of trees relative to agricultural crops or pasture. Applications of tree planting include both recharge control and discharge control of salting. Efficient design of planting plans for recharge control requires identification of the areas in each catchment where groundwater recharge is most intense. Tree planting should be considered as the primary control measure in these areas, and should also be integrated with modified farming practices to minimise groundwater recharge over the remainder of the catchment. The location and density of planting needed for effective control of recharge will usually allow continued agricultural production within the planted area.

Establishment of trees within groundwater discharge areas is more difficult and is unlikely to achieve long term salinity control unless recharge control is simultaneously applied, when discharge control will hasten the reclamation of salted land. The location and density of planting required depend on the characteristics of the discharge area, and further research would be necessary to gain a full understanding of the application of tree planting in these areas.

Species selected for salinity control planting must be able to make good growth on the site to be planted, to transpire large quantities of water, and to provide other products or benefits as far as possible. Choice of species should be made on the basis of experience and local knowledge, supplemented by consideration of ecological requirements. The development of agroforestry systems which combine tree growing with conventional agricultural production without economic disbenefit will assist in the necessary introduction of large numbers of trees into farming areas.

Tree planting has repeatedly been suggested as a means of controlling salinity in Victoria and elsewhere (Morris *et al.* 1981, Greenwood 1978, Garland & Duff 1981, Anderson 1982). Although some of the suggested applications of trees are unlikely to be feasible for either physical or economic reasons, it is now apparent that successful control strategies for dryland salting will probably include tree planting in combination with agricultural and engineering measures. The purpose of this paper is to examine what part trees might play in such a combined strategy.

The potential of some tree species to control salting lies in their ability to use more water than crops or pastures on an annual basis, and to draw it from deeper in the soil profile. The primary features contributing to this effect are an evergreen perennial habit and an extensive root system; other features of importance in some species include leaf area, canopy structure and physiological factors such as the ability to continue transpiring at relatively low soil water potential. Some indigenous eucalypts are particularly well suited for salinity control planting, in addition to being naturally adapted to the Victorian climate. Some measured rates of transpiration for eucalypts and other species are listed in Table 1. An aspect of canopy structure worthy of special mention is the capacity of tree crowns to intercept incident rainfall. This may rival transpirational water use as a means by which trees limit the amount of water percolating into the soil, particularly in areas or at times of the year when rain falls predominantly as light showers. In addition to their water use, the possibility of salt uptake by trees has been considered by some as a means of lowering soil salt concentrations. The rapid growth, large stem volume and ability of some species to resprout from a cut stump have led to suggestions of a system of short-rotation coppiced eucalypts, with salt-laden stems and foliage being harvested and removed from the site every few years. Appealing as such a scheme may be, the calculations in Example 1 show that it is clearly not feasible.

There are two distinct approaches to tree planting for salinity control. The first and most important is planting in groundwater recharge areas to reduce the volume of water passing beyond the root zone to replenish groundwater reserves; the second approach is to establish trees in discharge areas with the intention of lowering raised water tables by drawing on the groundwater for transpiration. The remainder of this paper is concerned with the question of where, how much and what species to plant for effective salinity control by each of these approaches.

RECHARGE CONTROL

Some groundwater recharge is likely to occur over virtually the whole area of most Victorian catchments, at least in wet years (Dyson & Jenkin 1981). However, the volume of recharge per unit area may vary greatly in both time and space. The amount of rainfall and evaporation, land use or vegetation type, topography, soil, and geology of a catchment all influence the quantity of water which enters the soil at a given point and passes through the profile to join the groundwater. Naturally, the larger the catchment under consideration, the more variation will be displayed in each of these factors and the more variation can be expected in groundwater recharge. Even in small catchments however it should be possible to define zones of greater and lesser

TABLE 1
SOME ESTIMATES OF DAILY AND LONGER TERM WATER USE BY EUCALYPTS AND OTHER SPECIES

Species	*Water Use*	*Notes*
Eucalyptus occidentalis	558 mm over 5 months of summer	12 year old plan-plantation. (Stibbe 1975)
Eucalyptus species	Up to 3 mm day^{-1} during summer	2 years post germination. (Greenwood & Beresford 1979)
Eucalyptus camaldulensis	562 mm $year^{-1}$	(Karschon & Deth 1967)
Mature eucalypt forest	Up to 739 mm over 16 months	(Carbon *et al.* 1982)
Eucalyptus wandoo	1100 mm $year^{-1}$	Based on projected canopy area of scattered trees (Greenwood *et al.* 1981)
Pinus pinaster	Up to 738 mm over 16 months	(Carbon *et al.* 1982)
Pinus pinaster	Up to 610 mm $year^{-1}$	(Butcher 1977)
Pinus radiata	910 mm over 14 months (up to 3.3 mm day^{-1})	(Greenwood *et al.* 1981)
Pinus radiata	726 mm $year^{-1}$	(Holmes & Colville 1970b)
Atriplex vesicaria	Up to 1.3 mm day^{-1} during summer	(Greenwood & Beresford 1980)
Pasture	588 mm $year^{-1}$	(Holmes & Colville 1970a)
Pasture	540 mm $year^{-1}$ (up to 4.1 mm day^{-1})	Greenwood *et al.* 1982)
Maize	Up to 6.5 mm day^{-1}	(Slabbers 1980; quoting other
Alfalfa	Up to 8.5 mm day^{-1}	workers)

recharge potential on the basis of slope and aspect. The importance of identifying areas of high groundwater recharge lies in the possibility of concentrating salinity control efforts in these areas. Methods are available for mapping recharge contours over large areas, based on indices such as soil moisture at depth, soluble ion content, earth resistivity or other measures of the degree of leaching. Such surveys are however expensive and at best it will be some years before extensive recharge data are available for the major salt-affected catchments of this state.

Rather than delay urgently-needed recharge control measures, it should be possible to identify major recharge areas where they exist by stratification of catchments on the basis of rainfall, vegetation, slope, aspect, and soil type, combined with existing knowledge of groundwater resources. Even a rough subjective classification along these lines should be adequate to point to the parts of a catchment where the hazard of recharge is greatest, thus allowing concentrated salinity control efforts to begin. The effects of non-uniform recharge on salinity control strategies are illustrated by the calculations in Example 2.

The distribution of groundwater recharge within a catchment may also vary from year to year. In some areas of low to moderate winter rainfall downward movement of water through the soil profile is limited by an impeding B horizon of low hydraulic conductivity. Groundwater recharge is therefore restricted, and in dry years could be confined to limited areas of shallow or coarse textured soils or bare fallowed ground. More commonly an impeding B horizon will tend to keep recharge uniform from year to year, as long as rainfall is sufficient to maintain the A horizon above field capacity through the winter. Rainfall in excess of the maximum drainage rate permitted by the impeding layer will then tend to be lost as surface runoff. This restriction of recharge is fortunate from a salinity control viewpoint, since extreme variation of recharge with time presents a problem for the design of control measures. For example, suppose it has been determined that salting in a given catchment is the result of an average increase in recharge of 20 mm per year since clearing of native forest. Strategies designed to reduce recharge by this amount may be ineffective if nine years of below average rainfall with zero excess recharge are followed by a tenth in which excess recharge is 200 mm.

The implications of recharge variability for land management in catchments subject to salting are clear. In the major or perennial recharge areas tree planting to maximise interception of rainfall and transpiration of soil water is an appropriate treatment: in many cases this will not conflict seriously with agricultural landuse since the recharge areas will tend to be on the shallow stony soils of hilltops and ridges (Jenkin 1981). In addition, agricultural practices in the rest of the catchment must be refined to allow more careful management of soil water storage. The aim should be to minimise the penetration of water beyond the maximum rooting depth of the crops or pastures grown; breeding of deeper rooted varieties of important species will help in the longer term. Thirdly, trees should be established as shelter belts, woodlots or ornamental plantings within the agricultural area, taking advantage of roadside verges and other unused land to remove some of the water stored at depth in the soil profile. By these measures the annual accession of water to the groundwater through major recharge areas will be halted or substantially reduced, and the extent of saturation of soils in the rest of the catchment minimised to provide reserve capacity for storage of water in periods of high rainfall.

Tree planting for regional recharge control is therefore of two types: 'primary' planting in the perennial recharge areas, and 'secondary' planting (combined with modified farming practices) throughout the cleared part of the catchment. The related questions of where and how much to plant in a given situation may be considered in terms of this classification. In general, the aim must be to plant where recharge takes place and to establish a large enough area of trees at sufficient density to eliminate this recharge.

The location and extent of primary planting are determined wholly by the size and location of identified perennial recharge areas: for effective control, trees must be planted within these areas and planting must extend over the whole area. The density of planting remains to be determined, and is of considerable importance as it affects the feasibility of combining tree establishment for recharge control with grazing, cropping or other landuse within recharge areas. To obtain the maximum benefit from interception of rainfall, trees must be planted closely enough to achieve more or less continuous crown cover over the whole recharge area. While this might be necessary in some limited areas of very high recharge, it is likely that the water-using capacity of tree species chosen for recharge control will usually be great enough to utilise all the infiltrating water in transpiration; interception is then a non-essential benefit of tree establishment, and tree spacing may be increased as long as continuous root cover over the whole recharge area is achieved.

It is important to appreciate that the planting density in recharge control areas need not be as high as that of the native forests which grew there before clearing. In the natural situation, the water use of individual trees is limited by water availability in the presence of competition from adjacent trees (Figure 1). As a result, total water use per unit area may be expected to be independent of tree density over a wide range. Furthermore, the use of selected high water-using species or varieties, and the application of management practices such as thinning and coppicing should allow an increase in the annual potential transpiration rate over that of the native forest. In any case, the aim of eliminating groundwater recharge within identified perennial recharge areas is an ideal which need not be wholly achieved: a complete return to pristine conditions of groundwater recharge, watertable level or stream salinity in farmed catchments is not necessary to overcome dryland salting and restore stream water qualities to an acceptable standard. The relation between potential tree water use and the proportion of a catchment retained under forest is examined further in Example 3.

The location and extent of secondary planting for reduction of ephemeral recharge over large cleared areas are strongly influenced by the availability of land and the willingness of landholders to establish trees as shelter belts, woodlots, ornamentals or for other purposes within prime agricultural areas. Tree establishment should be concentrated in those parts of a catchment where the risk of a substantial 'overflow' of soil water into the groundwater is greatest. The characteristics of such high-risk areas are similar to those of perennial recharge areas, including high effective rainfall, relatively coarse textured soils, low slopes and shallow groundwater.

Fig. 1—Expected form of the relationship between tree density and water use per unit area for high (solid line) and low (broken line) levels of potential transpiration.

The density of this type of tree establishment will rarely be sufficient to remove all the water stored or penetrating below pasture and crop root zones. The aim should be to plant as many trees as possible, without reducing agricultural productivity. There are undoubtedly many opportunities for tree planting within this constraint on most Victorian farms, and on public land in agricultural districts. Possibilities include roadsides, easements, reserves, land too steep, stony or boggy for economic agricultural use, and around homesteads. To these may be added deliberate commitments of farm land for tree growing for a specific purpose, including shelter belts and woodlots producing firewood, round timbers, pulpwood or sawlogs. In every case, benefits will accrue to the landholder and the local community, not only through salinity control but by providing shade, shelter, landscape amelioration and wildlife habitat in addition to harvestable tree products.

DISCHARGE CONTROL

Efforts to overcome dryland salting have in the past been directed mainly at treatment of the affected area to re-establish vegetation, limit surface evaporation and promote leaching. Although discharge control measures such as these are a natural first approach, the greater importance of recharge control is now widely recognised (Williamson 1981, Jenkin 1981). The vegetative cover established by careful treatment of a salt seep is at best a fragile pasture which can survive only slight grazing and must be managed separately from adjacent land; leaching of salt seep soils is often hindered by a tendency of the soils to disperse and prevent infiltration as soon as fresh water is applied. In any case leaching without deep drainage or recharge control is likely to add to the problem by further raising the watertable below a seep.

Where salting is the result of a high regional watertable, localised controls will not be adequate in the long term: new outbreaks may occur outside the range of the control measures. The use of trees as 'biological pumps' for discharge control may even aggravate the problem in the longer term, by increasing the concentration of salt in the groundwater; on the other hand, pumping and drainage may lead to difficulties with the disposal of saline groundwater brought to the surface. It is apparent that control measures which do not rely on perpetual removal of groundwater from discharge areas, but rather are aimed at changing the hydrologic balance so that watertables move towards an equilibrium level well below the surface, are to be preferred.

Nevertheless, establishment of trees in discharge areas may be useful when combined with recharge control measures. The high annual water use and deep rooting habits of trees and the ability of some species to draw on the groundwater provide a means of lowering raised watertables in discharge areas more rapidly than may be possible otherwise. If recharge control is practised at the same time, it should be possible to stabilise the watertable below the root zone at a depth sufficient to eliminate surface discharge by capillary rise. Any increase in groundwater salinity which occurs in the interim period is therefore limited in significance, since it will no longer be necessary for vegetation to draw on this supply of water. The calculations of Example 4 illustrate the possible application of trees in a discharge control situation.

The combination of waterlogging and salt accumulation in the upper soil profile will rarely allow trees to establish and make good growth in the central, most severely affected part of a salt pan or seep. Planting may be recommended with confidence only where the cover of grasses and herbs is greater than 75%, the remainder being bare or inhabited by halophytic shrub species. Tree planting for discharge control will thus tend to surround the obviously salinised area; within the salinised area, salt tolerant grasses or shrubs could be established to reduce surface evaporation and prevent erosion. These may be replaced by a denser cover of less salt tolerant species after the watertable begins to fall and salt is leached and washed away from the surface.

Saline discharges take several different forms, and the effectiveness of control measures may vary from one to another. In particular we should distinguish the case of an unconfined or perched aquifer near the surface, from that of a deeper semi-confined aquifer discharging under pressure. A second important distinction may be made on the direction of groundwater movement to the discharge area: the case of lateral flow to the seep should be separated from that of a shallow aquifer recharged from below by upward movement of water stored in deeper strata.

For trees planted around a seep to lower the watertable, the groundwater must be accessible to their roots and of low enough salinity to be tolerated by them. Accessibility to roots requires the absence of strongly impeding horizons between the groundwater and the surface; thus it may not be possible to control discharge from a semi-confined aquifer by this approach. The maximum depth to which roots will penetrate and the maximum salinity tolerated depend on tree species and soil factors, and are at present poorly known; approximate upper limits may however be conservatively estimated as 15-20 metres depth and 8000-12 000 ppm of total dissolved salts.

Any lowering of the watertable which results from tree establishment around a seep will be a local effect, forming a groundwater depression analogous to the drawdown zone around a bore from which water is pumped. The steepness of the sides of this depression depends on the soil hydraulic conductivity; thus in heavy clay soils of low conductivity the effect of tree planting around a seep will not extend far beyond the edge of the planted strip. Under these conditions only small seeps can be wholly reclaimed by peripheral tree planting. However, over a period of 10-20 years it should be possible to reclaim larger areas by additional planting gradually advancing inwards from the original boundary of the seep.

The lateral movement of water from recharge to discharge areas requires either soils of high lateral hydraulic conductivity, or flow pathways through deep leads, shoestring sands, or fissured bedrock. Dryland salting in Victoria is typically associated with soils of low hydraulic conductivity (Dyson & Jenkin 1981); thus water movement is predominantly downwards in recharge areas and upward in discharge areas and there is little opportunity to intercept lateral groundwater flow by tree planting or other means. In situations where lateral flow pathways can be located and are accessible to tree roots, the limitations described in the previous paragraph do not apply. By establishing a sufficient number of trees in the appropriate location, the lateral flow of groundwater to the discharge area can be diverted into a transpiration flow through the trees and the salinised area reclaimed.

What constitutes 'a sufficient number of trees' for this or other discharge control planting is however difficult to determine. Even if the annual water use of individual trees can be reliably estimated, the rate of groundwater flow to the discharge area usually remains unknown. The extent to which roots intercept the lateral flow or the upward movement of groundwater, the effects of salt accumulation on tree water use and the ability of roots to draw on a semi-confined aquifer discharging under pressure are at present unknown factors, but together they determine the number of trees which must be planted for successful discharge control. A simple first approach is to measure or estimate the annual outflow of a seep and plant enough trees to use this amount of water, based on their expected individual water use under the prevailing site conditions. In fact, somewhat more than this number of trees must be planted if a lowering of the watertable is to be achieved rather than just a reduction of the outfall to zero. This approach assumes that the trees completely intercept the flow of groundwater to the seep, or draw directly on the aquifer supplying the saline water. If it is possible for tree roots to penetrate a semi-confined aquifer discharging under pressure, the effect of their water uptake on the rate of seepage will depend on the static head of water in the aquifer.

Clearly further research, in the form of both theoretical studies and empirical field trials, would be necessary to gain a full understanding of the circumstances in which discharge control by tree planting is feasible and the means of achieving it. However, it is unlikely that such detailed research into discharge control is justifiable in view of its limited application. Scarce research funds are for the time being better directed toward the evaluation of species for recharge control planting, the economics of combined agricultural and tree planting control strategies, and the location of major recharge areas.

SELECTION OF TREE SPECIES

There are three main criteria to take into account when selecting tree species for planting in catchments with salinity problems. These are:

1. adaptation to site—the ability to establish, grow and maintain a healthy condition over an extended period;
2. the capacity to transpire large quantities of water, including the ability to tap the groundwater where appropriate;
3. the provision of economic and other benefits in addition to the lowering of watertables and control of salinity.

Adaptation to Site

Because dryland salinity is widespread the range of environments into which trees may be planted is considerable. There is a need to identify major site types and define them in terms of environmental factors of importance to tree survival and growth. In particular, hilly or undulating country may require stratification on a local or micro-scale. A single species is unlikely to succeed, or at least be the most desirable species, over all the site types under consideration.

Although dryland salting in Victoria commonly occurs in areas of relatively low rainfall (Anon. 1982), the selection of trees for salinity control planting is by no means confined to dry country species. The perennial recharge areas in which clearing of native forest has contributed most to raised regional watertables are likely to be found in the upper reaches of major catchments, with rainfall up to 1 000 mm or more per annum. The range of sites where trees may be planted for salinity control extends from these areas of potentially high productivity to saline soils in low rainfall groundwater discharge areas where survival of the planted trees is the best that can be aimed for, and there is little prospect of economic production.

It is therefore apparent that there will be a wide range of tree species of potential use in the control of salinity. To determine the range of site conditions in which promising species make good growth, it is desirable that field trials of selected species be established on a number of sites covering the range of conditions in which salinity control planting is likely to be undertaken. Since a reliable assessment of species performance may not be made for some years after planting, these trials should be commenced as soon as possible.

A rationale for the choice of species for field screening should include both theoretical and empirical approaches. The theoretical approach entails the selection of potential species from environments with similar climatic and edaphic regimes to those of the environment of introduction. Species which overlap a wide range of environment such as *Eucalpytus camaldulensis* Dehnh. (river red gum) and *Acacia melanoxylon* R. Br. (blackwood) are also obvious candidates for inclusion.

The empirical approach draws from the reservoir of local knowledge and a study of previous plantings and indigenous vegetation. A considerable body of knowledge is already held by government departments and individual landholders as to the tree species most likely to grow well under given local conditions. Indigenous vegetation merits special consideration because of its long period of adaptation to and evolution with the local environment. Remnant patches of native vegetation enable an accurate and quick assessment of the potential of indigenous species in revegetation. These species have the advantages of low maintenance and natural regeneration when re-established as viable patches of forest with component understorey species. Some degree of protection from grazing is necessary to maintain the integrity of such ecosystems. Occasionally man-induced changes will render an indigenous species unsuitable for replanting, for example *Eucalyptus macrorhyncha* F. Muell. ex Benth. (red stringybark) will not persist in grazed areas due to ringbarking by stock. On a broad scale, dieback and death of isolated eucalypts in the rural landscape, from a variety of causes, indicates the instability of such systems (Kile *et al.* 1980).

Combining the theoretical and empirical approaches may lead to a finer resolution of species choice. For example preliminary empirical investigations may indicate *Eucalyptus globulus* Labill. (southern blue gum) to be a suitable species for planting in wetter areas. A study of the natural occurrences of this species and its subspecies may then indicate the existence of populations adapted to dry, saline or waterlogged sites. Collection of seed from these populations could lead to a considerable extension of the planting range of this species. Once the potential of a species for widespread planting has been recognised, more intensive forms of selection including screening and breeding for desired characteristics may follow. Vegetative propagation (cloning) provides a suitable technique for capitalising on the gains of selection and breeding. For example, seedlings of *E. camaldulensis* have been selected for sodium chloride tolerance and vegetatively propagated to provide planting stock for saline sites (Ralph 1981).

Capacity to Transpire Large Quantities of Water

The major objective of planting trees in salinity-prone catchments is to lower watertables. Therefore species selected should be those which will transpire and intercept maximum quantities of water. This is true whether the trees are planted to reduce groundwater recharge by absorbing soil water and thus preventing deep percolation, or to draw directly on the groundwater by root proliferation within the capillary fringe.

Trees have evolved in environments of differing moisture regimes and as a result individual species tend to operate at different levels of carbon assimilation and water loss. These levels have been described as ranging from adventurous (high rates of carbon assimilation and consequently transpiration; exemplified by many eucalypts) to conservative (low rates of carbon assimilation and transpiration, as displayed by *Casuarina* species) (Ashton *et al.* 1975). Greenwood and Beresford (1979) have directly measured transpiration rates in young eucalypts using a ventilated chamber technique. Their results indicate that there are significant differences in transpiration rates between different species but that the rankings change with age and vary between sites. Investigations of leaf area index in eucalypt stands in southwestern Australia suggest that five-year-old regrowth may have a leaf area index equivalent to that of mature forest (Carbon *et al.* 1979). This suggests that some eucalypt stands may reach their maximal transpiration capacities at an early stage in stand development. This fact should be taken into account when assessing the potential for replanted trees to modify the hydrological characteristics of a catchment.

For the purpose of maximizing water use it is desirable to select species which exhibit adventurous characteristics. However, it is imperative that tree species are planted only on sites which can meet their requirements. For example, seedlings of *E. globulus* planted above a saline seep in southwestern Australia grew prolifically for several years but during a dry period some saplings suffered dieback and death. Subsequently most saplings staged a recovery, but the lesson of growing species only on suitable sites remains. Research is required to elucidate a, those species which can utilize maximal quantities of water for different site types, but survive when conditions become adverse; and b, those species which predominantly use groundwater in supplying their moisture requirements. These species have the advantages of having access to a more or less permanent supply of water and importantly providing minimal competition to crop plants for top soil moisture.

It is apparent that species which grow rapidly, develop high leaf area indices and exhibit mesophytic characteristics are the prime candidates for this research.

Benefits other than Salinity Control

Where several species are available which fulfil the adaptability and water use criteria, these species should be screened for their potential to supply economic and other benefits. Some products associated with tree growing which provide easily measured economic benefits include sawn timber, pulp, fuelwood, eucalyptus oil, livestock fodder and honey. Other benefits such as shade, shelter, nutrient cycling, erosion control, landscape amenity and wildlife habitat are less easily quantified; these benefits will vary with location and individual farmers will attach different importance to them.

The tendency of trees to adversely affect adjacent pasture varies between species, and this may be a factor in selecting species for agroforestry enterprises (Anderson 1982).

The introduction of trees in large numbers into agricultural areas will be favoured if tree growing can be integrated with conventional farming practices without economic disadvantage. Some examples of schemes which may prove to be of benefit to landowners in the recharge zones of salt-prone catchments are a, the establishment of *Pinus radiata* D. Don (radiata pine) woodlots or incorporation of this species in an agroforestry system (Anderson & Batini 1979). The high growth rates, adaptability to a wide range of sites and forestry potential of this species should allow economic wood production as well as reduction of groundwater recharge; b, in the 400-500 mm rainfall belt an agroforestry system consisting of *E. polybractea* R. T. Baker (blue mallee) and *Medicago sativa* L. (lucerne) producing both eucalyptus oil and pasture (Anon. 1976). The ability to clone the high oil yielding varieties of *E. polybractea* would considerably enhance the economics of this system; c, fast growing eucalypts planted along drainage lines in midslope positions could yield sawn timber, farm timbers and fuelwood. In wetter zones *E. globulus* and subspecies, and *E. viminalis* Labill. (manna gum) show promise while in lower rainfall areas *E. camaldulensis* and *E. occidentalis* Endl. (yate) may be the most useful species.

In saline discharge areas where the groundwater is known to be accessible and not excessively saline, the planting of salt tolerant *E. camaldulensis*, *E. occidentalis* and possibly other species on and adjacent to salt affected land may lower local watertables, minimise soil erosion and provide forest products. The development of salt tolerant clones of eucalypts is a new and exciting prospect; however, these clones will require field testing over a period of time before their merits can be reliably assessed. If the clones prove useful then the establishment of clonal plantations will need to be based on a wide range of clones, because of the inherent dangers of establishing large areas of genetically uniform plant material.

CONCLUSION

While tree planting will only form one part of the control strategy for dryland salting in any catchment, it represents a readily available and highly flexible means of reducing the excessive intake and storage of groundwater responsible for raised watertables in many areas of Victoria. The technical difficulties of designing and implementing a large scale tree planting scheme are not great, but the economic problems are formidable, especially where planting is required on productive agricultural land. More work is needed to determine estimates of the costs of realistic salinity control strategies in representative areas, and to explore possible funding arrangements and incentives for salinity control measures including tree planting on farms in salt-affected catchments.

Further research is also required to define the modified agricultural systems which may be employed to minimise recharge from farmland, and determine their effectiveness for this purpose. However, because of the continuing expansion of salt-affected areas and the high cost of lost production from them it is vital that detailed planning and implementation of control strategies for major catchments begin as soon as possible on the basis of existing knowledge, rather than awaiting the outcome of what may well be long term research studies.

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APPENDIX

Example 1. Potential of Trees for Desalination of Saline Soils.

(a) Foliar salt content of eucalypt foliage under saline conditions:

Field trials have shown chloride content of several eucalypts and other native species on a highly saline site stabilises at 1-1.5% of dry weight. This corresponds to a sodium chloride content of about 1.6-2.4%, or 2% as an average figure.

(b) Biomass accumulation by planted eucalypts:

Taking fertilised *Eucalyptus grandis* W. Hill ex Maiden (flooded gum) as a source of optimistic growth estimates (Bradstock 1981)—

Total biomass at age $2 = 1.8$ kg m^{-2}
at age $11 = 8.4$ kg m^{-2}

(c) Potential salt uptake:

Assuming stem salt concentration is similar to foliar concentration (approximately 2% of dry weight) the expected salt uptake by trees on a saline site is:

36 g m^{-2} after 2 years
168 g m^{-2} after 11 years

(d) Salt storage in the soil:

For a moderately saline clay soil containing 0.2% salt, with bulk density of 1.2, salt content is 2.4 kg m^{-3}. Thus for a soil depth of 1 m this soil contains 2.4 kg m^{-2} NaCl.

Desalination by harvesting of eucalypts would thus require about 70 two-year rotations or about 14 eleven-year rotations, assuming no more salt enters the profile in that period.

Example 2. Estimation of Recharge Rates and Areas in a Closed Catchment.

Consider a catchment with a total area of 120 ha, in which groundwater discharge takes place at 100 mm per year over a 20 ha discharge area. Assume that all of this groundwater comes from uniform recharge over the remaining 100 ha; there is no groundwater flow into or out of the catchment.

Annual discharge = annual recharge
= 2000 ha mm or 20×10^6 litres

and recharge over the upper catchment area is 20 mm per annum; it should be possible to prevent this recharge simply by modifying agricultural practices, thus overcoming the discharge problem.

Now suppose recharge is not uniform: let 90% of recharge occur on a limited area of 10 ha, while the remainder is evenly distributed over the other 90 ha.

Recharge rates are now 180 mm per annum on the intense recharge area, and 2.2 mm per annum in the diffuse recharge zone. Modification of existing land use practices is unlikely to be sufficient to control recharge in the intense area, but the establishment of trees there could enable control.

Alternatively, suppose the annual rainfall in the recharge area is a uniform 400 mm. If it is suspected that an intensive recharge zone exists, its maximum area can be estimated. Assuming that say 50% of rainfall on the intense recharge zone is lost as runoff or evaporation, the actual recharge rate there is 200 mm per annum. This will provide all of the 2000 ha mm of discharge if its area is 10 ha. A rough calculation such as this may be helpful in planning the scale of tree planting needed for recharge control of salinity in a catchment.

Example 3. Relating Recharge Planting Areas to Potential Forest Water Use.

Consider a forested catchment of area H ha in which no recharge takes place. C ha are now cleared for agriculture, and groundwater recharge takes place over this area at R mm per year. The volume of annual recharge from the catchment is RC ha mm.

If the actual water use of the forest area is A mm per year and its potential water use given an unlimited water supply is P mm per year, then the unused transpirational capacity of the forest is $(P-A)(H-C)$ ha mm per year.

Assuming free movement of soil water from the cleared area to the root zone of the remaining trees, no groundwater recharge will occur as long as $RC \leq (P-A)(H-C)$, that is, as long as:

$$\frac{C}{H-C} \leq \frac{P-A}{R}$$

From this formula we may calculate the minimum proportion of a catchment to be retained or replanted as forest, for an expected value of potential tree water use. For example, suppose $A = 500$ mm per annum and $R = 20$ mm per annum; establishment of trees on 5% of the catchment will be sufficient to prevent groundwater recharge if P is at least 880 mm per annum. This potential water use is not unrealistic given the measured transpiration rates of well watered trees.

Tree cover of 5% is afforded by a series of three or four row windbreaks 10 m wide at intervals of 200 m across the catchment; however, the assumption of free movement of soil water to the tree root zone would not be met under these conditions.

Example 4. Modelling the Effects of Tree Planting on Groundwater Salinity and Discharge.

Consider a discharge area 1 ha in extent. The aquifer beneath this area contains 50 Ml of water at a salinity of 6000 ppm total dissolved salts (a 10 m aquifer thickness, assuming 50% porosity). We may study the effects of different inputs and outputs of groundwater with the aid of a simple model:

$$S_n = \frac{S_{n-1} \cdot V_{n-1} + I_n \cdot C - O_n \cdot S_{n-1}}{V_n}$$

$$V_n = V_{n-1} + I_n - O_n - T$$

where S_n = groundwater salinity in year n
V_n = volume of groundwater in aquifer in year n
I_n = groundwater inflow to discharge area in year n
O_n = groundwater outflow from aquifer in year n
C = inflow salinity (6000 ppm)
T = annual water use by trees

Four cases may be considered:

(a) inflow constant, 5 Ml per year at 6000 ppm. Trees in the discharge area transpire 5 Ml per year, no other discharge occurs.
(b) inflow as above. Trees transpire 3 Ml per year, flow beyond the discharge area and loss to deeper aquifers total 2 Ml per year.
(c) transpiration and outflow as in (b). Inflow is affected by recharge control in the upper catchment: volume decreases by 0.5 Ml per year while salinity remains constant at 6000 ppm.

(d) recharge control applied as in (c). No tree planting in discharge area; to the 2 Ml of outflow is added a surface seepage flow of 3 Ml per year, decreasing by 0.5 Ml per year in line with recharge.

After 10 years, the volume and salinity of groundwater in the discharge area are:

(a) 50 Ml at 12 000 ppm
(b) 50 Ml at 9016 ppm
(c) 22.5 Ml at 12 345 ppm (watertable lowered by 5.5 m)
(d) 45 Ml at 6000 ppm (watertable lowered by 1 m)

A comparison of results (a) and (b) shows that, while discharge area tree planting increases the salinity of groundwater, the increase is slower where flow pathways exist for movement of groundwater beyond the discharge area.

Results (c) and (d) demonstrate the effectiveness of discharge area planting in conjunction with recharge control measures. The increase in groundwater salinity in case (c) may well be acceptable in view of the greatly lowered watertable. Leaching of the surface soil and establishment of useful vegetation in the former discharge area could be safely carried out; water use by the trees in this area is no longer required.

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